Building Life-Cycle Assessment

Weimin Wang, Ph.D., Assistant Professor
Department of Engineering Technology
UNIVERSITY OF NORTH CAROLINA CHARLOTTE

Acknowledgement

Sponsor:

U.S. Department of State

USASCP
U.S.-ASEAN SMART CITIES PARTNERSHIP

Partners:

UNIVERSITAS GADJAH MADA

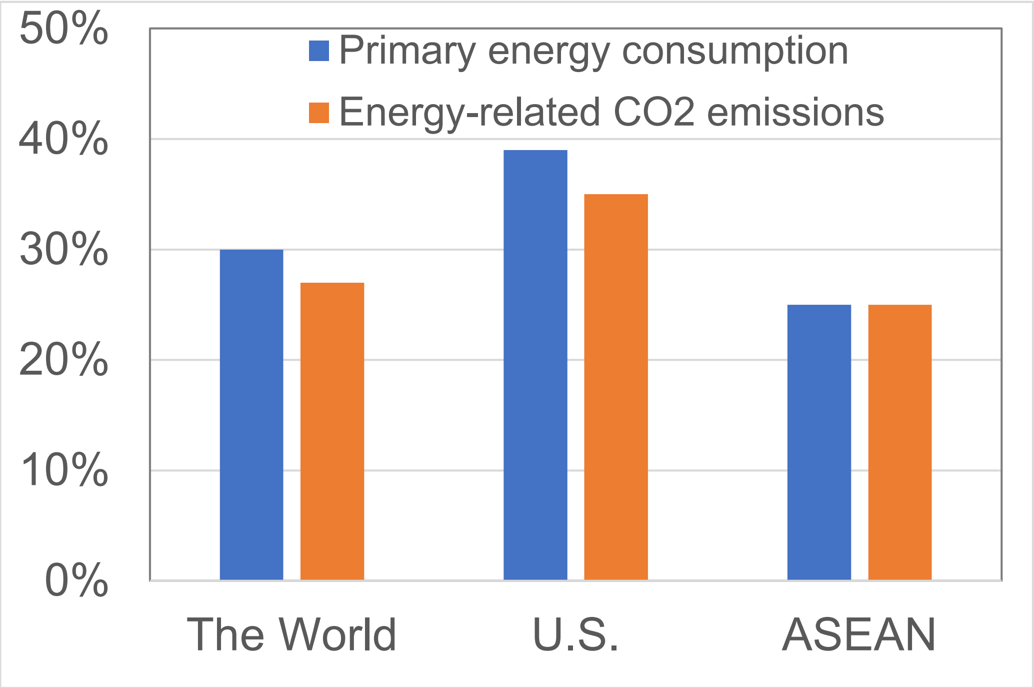
BK TP.HCM
Ho Chi Minh City University of Technology

Chula
Chulalongkorn University

Building and Environment

The building sector

- accounts for a large percentage of total energy consumption.
- has a large carbon footprint and a big impact on our environment.



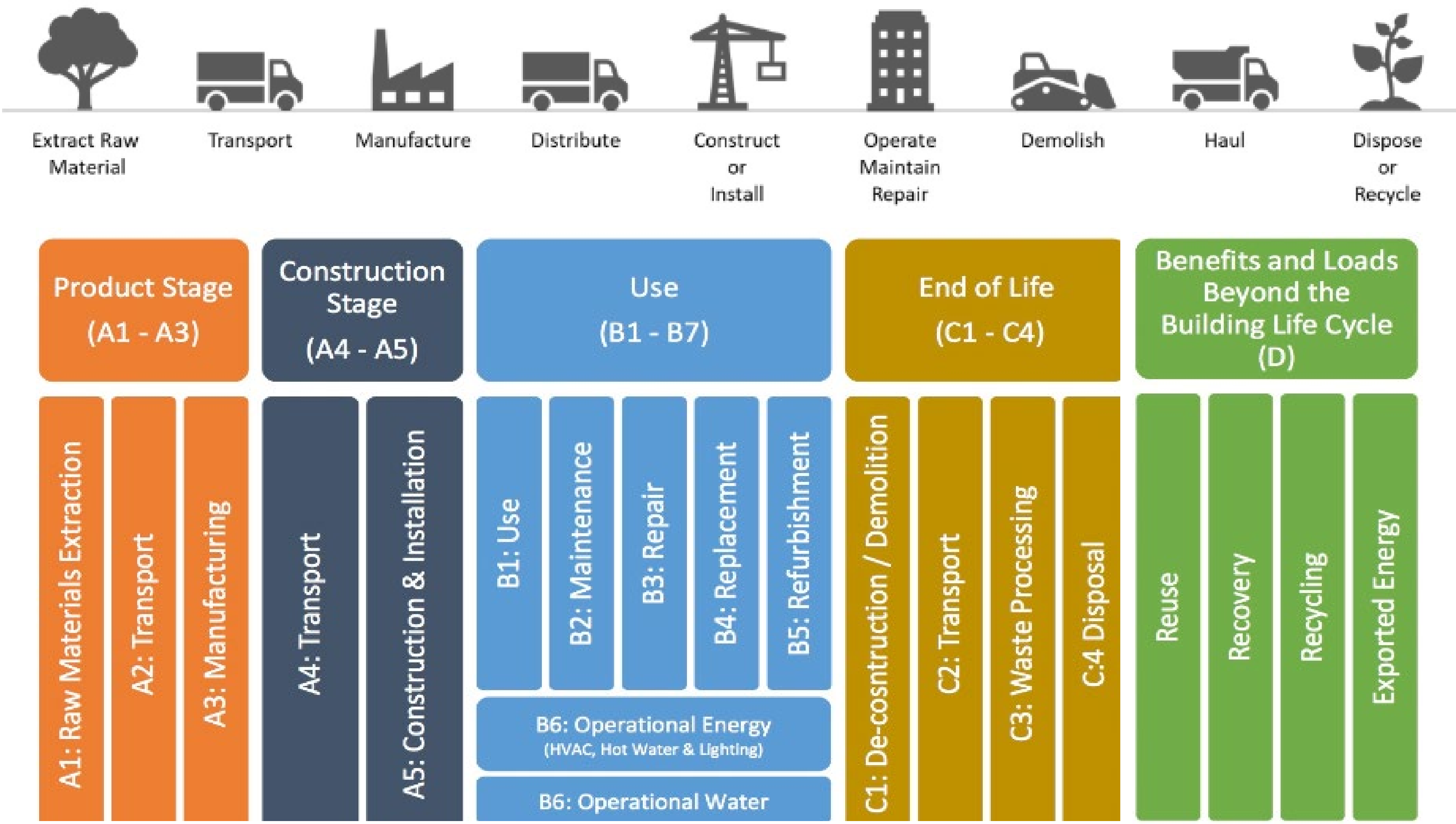
Sources:

- IEA (2022), https://www.iea.org/reports/buildings
- IEA (2022), https://www.iea.org/reports/roadmap-for-energy-efficient-buildings-and-construction-in-the-association-of-southeast-asian-nations
- EIA (2022), https://www.eia.gov/energyexplained/use-of-energy/

Building Environmental Performance

- How to evaluate?

Building Life Cycle Stages

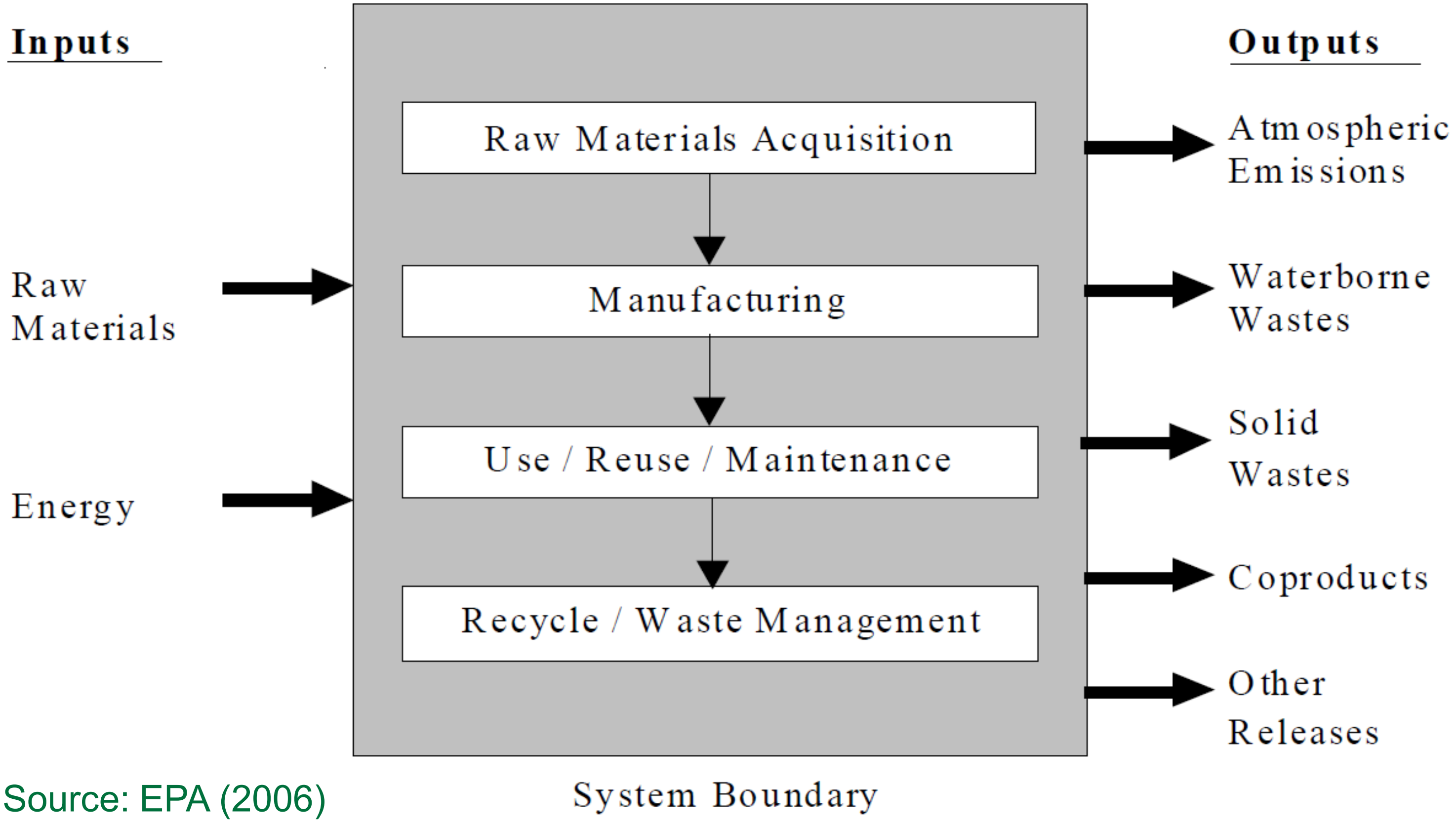


Sources:

- European Standard EN 15978:2011
- U.S. General Service Administration, https://sftool.gov/plan/399/life-cycle-perspective-life-cycle-thinking

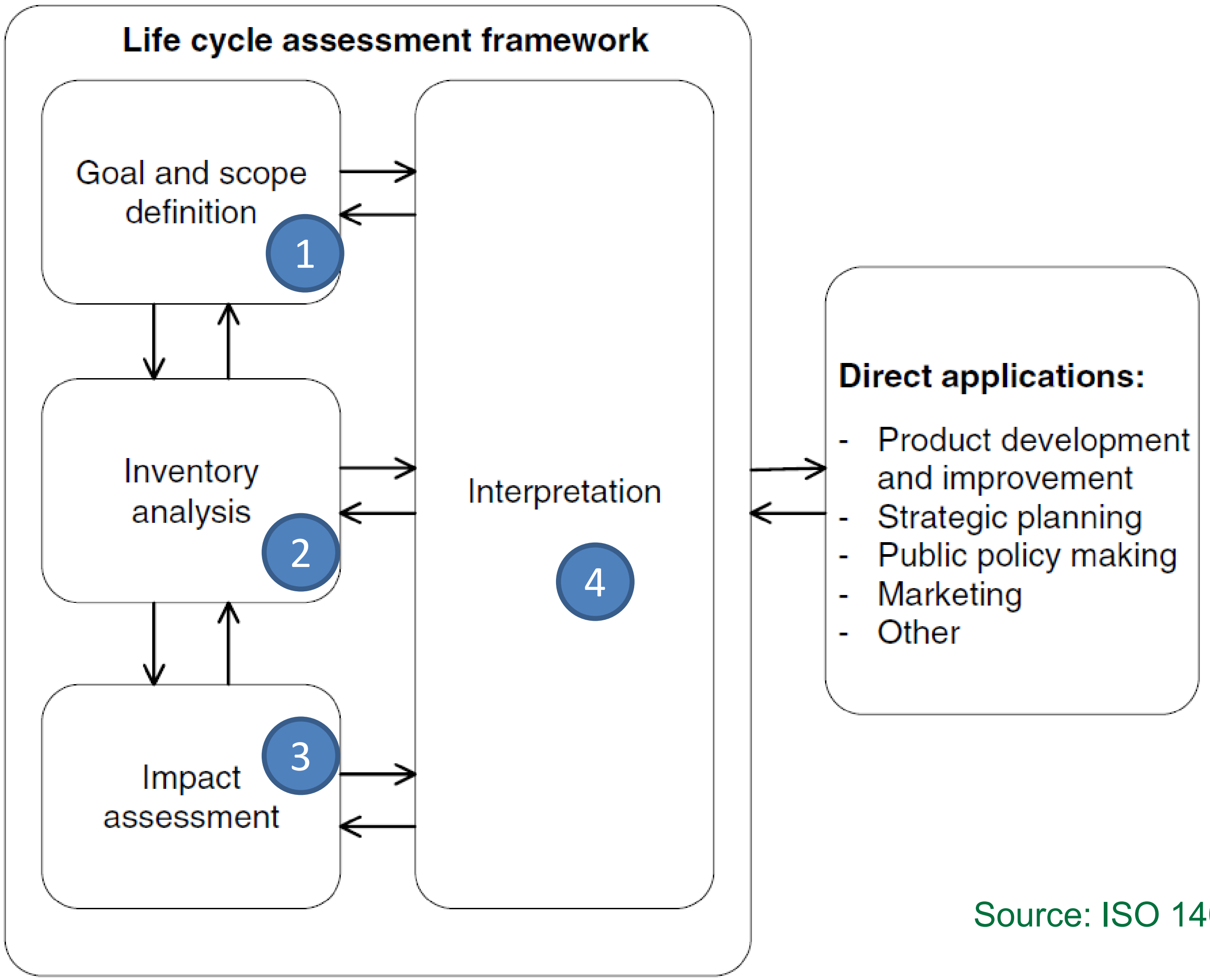
Life-Cycle Assessment (LCA)

- LCA is an approach to compile and evaluate the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.



Source: EPA (2006)

LCA Components



Source: ISO 14040 (2006)

1 Goal and Scope Definition

Define the purpose, the type of analysis, impact categories to be evaluated, and data to be collected.

- The Object of Assessment
- Functional Unit: LCA results can be compared on a one-to-one basis.
- System Boundary: the breadth and depth of the proposed LCA.

The Object of Assessment

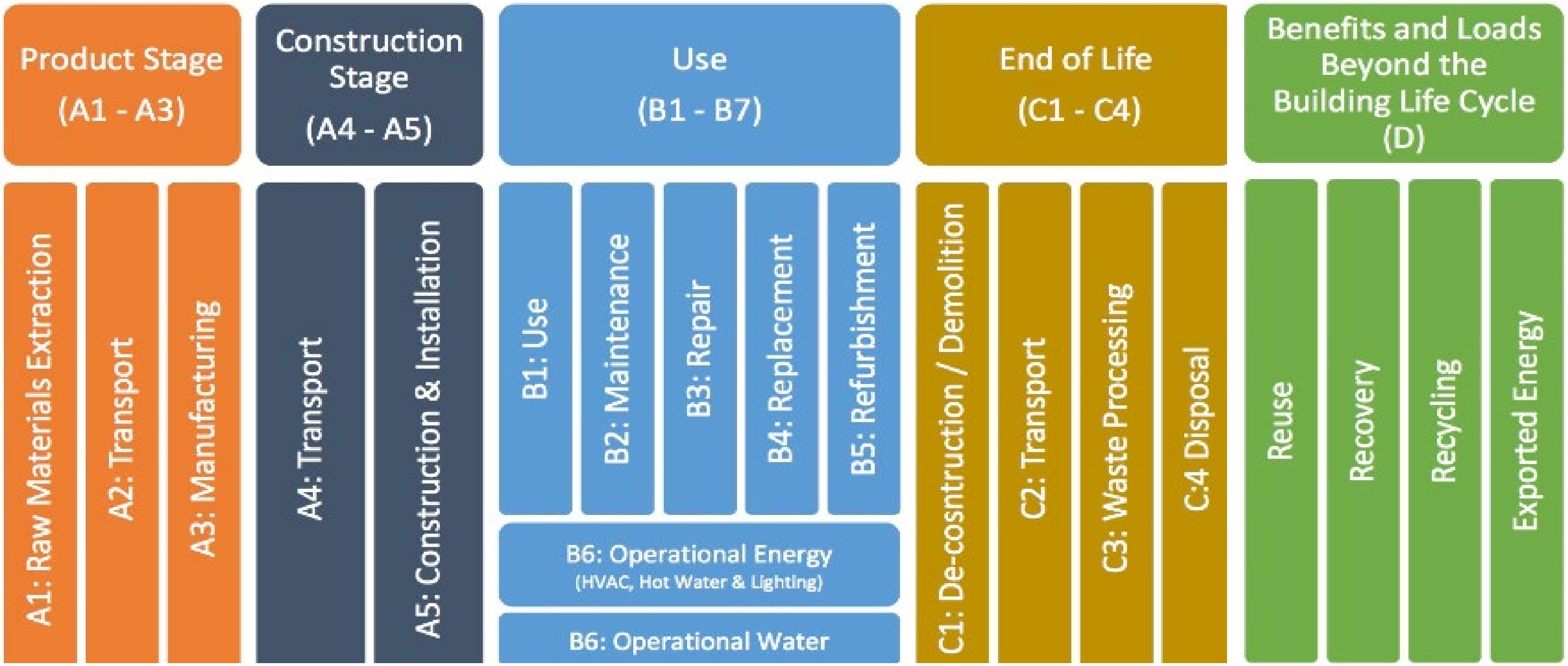
- Product
- Assembly
- System
- Whole building

Functional Unit

- Equivalent use: an equal amount of product or service to the customer.
- Examples:
  - Floor cleaning product
  - Floor coverings
  - Insulation materials
  - Concrete
  - Lamps
  - Building

System Boundary: Stages Covered

- Cradle to Gate (A1-A3)
- Cradle to Grave (A1-A5, B1-B7, and C1-C4)
- Cradle to Cradle (A1-A5, B1-B7, C1-C4, and D)
- ……



2 Inventory Analysis

- An inventory of all inputs to and outputs from the production system is prepared.
  - Inputs: energy, non-energy resources
  - Outputs: emissions to atmosphere, water and soil
- The most resource-intensive process of LCA
- Life-Cycle Inventory (LCI) Databases
  - Usually for unit processes
    - A unit process is the smallest element considered in LCI analysis for which inputs and outputs are quantified.
  - Be specific to countries and regions
  - Specific manufacturer vs. Industry average

LCI Example

- U.S. Life-Cycle Inventory Database: https://www.lcacommons.gov/lca-collaboration

3 Impact Assessment

Evaluate the potential human health and environmental impacts of the inputs & output identified from the life-cycle inventory (LCI) analysis.

- Select and define impact categories
- Classification
- Characterization
- Normalization (optional)
- Grouping (optional)
- Weighting (optional)

Impact Categories

Commonly used impact categories include:

- Global Warming
- Ozone Depletion
- Acidification
- Eutrophication
- Smog Formation
- Human Health
- Ecotoxicity
- Fossil Fuel Use
- Land Use
- Water Use

Source: EPA TRACI 2.1 (2012)

Classification

Organize and combine LCI results into impact categories.

- An LCI item contributes to one impact category
- An LCI item contributes to two or more impact categories
  - When the effects are dependent on each other, allocate a representative portion of the LCI result to the impacts categories to which they contribute.
  - When the effects are independent on each other, assign the LCI result to all impact categories to which they contribute.

Example: Global Warming

The substances normally considered as contributors to global warming are:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxides (N_2O)
- CFC's (CFC-11, -12, -113, -114, -115)
- HCFC's (HCFC-22, -123, -124, -141b, -142b)
- HFC's (HFC-125, -134a, -152a)
- Halons
- Tetrachloromethane (CCl_4)
- 1,1,1-Trichloroethane (CCl_3CH_3)

Example: Acidification

The substances normally considered as contributors to acidification are:

- sulfur dioxide (SO_2)
- sulfur trioxide (SO_3)
- nitrogen oxides (NO_x)
- hydrogen chloride (HCl)
- nitric acid (HNO_3)
- sulfuric acid (H_2SO_4)
- ammonia (NH_3)

Characterization

- Use characterization factors (equivalency factors) to convert and combine LCI results into representative indicators of impacts to human and ecological health.
- Make it possible to compare the LCI results within each impact category.

$$Category\ Indicator\ Result = \sum_i (CF_i * m_i)$$

Where,

- CF_i: Characterization factor for substance i
- m_i: mass for substance i.

Example: Global Warming Potential (GWP)

- GWP measures how much energy the emissions of 1 ton of a greenhouse gas will absorb over a given period of time, relative to the emissions of 1 ton of CO_2. ➔ CO_2 Equivalent
- The time period usually used for GWP is 100 years.

Greenhouse Gas	100-Year Time Period				20-Year Time Period			
	AR4 2007	AR5 2014		AR6 2021	AR4 2007	AR5 2014		AR6 2021
	Feedback Not Included		*Feedback Included*		*Feedback Not Included*		*Feedback Included*	
CO_2	1	1	1	1	1	1	1	1
CH_4 fossil origin	25	28	34	29.8	72	84	86	82.5
CH_4 non fossil origin				27.2				80.8
N_2O	298	265	298	273	289	264	268	273

Source: https://www.ercevolution.energy/ipcc-sixth-assessment-report

Related Tools

- EPA Greenhouse Gas Equivalencies Calculator

  https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator#results

- EPA Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI)

  https://www.epa.gov/chemical-research/tool-reduction-and-assessment-chemicals-and-other-environmental-impacts-traci

Normalization

- Express impact indicator data in a way that can be compared among impact categories.
- An optional step
- This can be achieved by dividing the impact category value by a selected reference quantity.
  - The total emissions or resource use for a given area (global, regional or local)
  - The total emissions or resource use for a given area on a per capita basis
  - The ratio of one alternative to another (i.e., the baseline)

Example: Normalization References

Impact Category	U.S. Total per Year	Units	Source
Global Warming	7.4 E+12	kg CO_2 eq	Ryberg (2014)
Primary Energy Consumption – Non-Renewable	2.544E+13 (9.16E+13)	kWh (MJ)	EIA (2018)
Primary Energy Consumption – Renewable	3.222E+12 (1.16E+13)	kWh (MJ)	EIA (2018)
HH Criteria Air	7.4 E+10[9]	kg $PM_{2.5}$ eq	Ryberg (2014)
HH Cancer*	1.57E+04	CTUcanc.	Ryberg (2014)
Water Consumption	3.883E+14 (1.026E+14)	L (gal)	USGS (2018)
Ecological Toxicity*	3.32E+12	CTUe	Ryberg (2014)
Eutrophication	6.6E+09	kg N eq	Ryberg (2014)
Land Use	9.15E+12 (2.26E+09)	m^2 (acre)	CIA (2018)
HH Non-cancer*	3.21E+05	CTUnon-canc.	Ryberg (2014)
Smog Formation	4.2E+11	kg O_3 eq	Ryberg (2014)
Acidification	2.8E+10	kg SO_2 eq	Ryberg (2014)
Ozone Depletion	4.9E+07	kg CFC-11 eq	Ryberg (2014)
Indoor Air Quality	1.08E+10	kg VOC	NIST (2010)
U.S. Population (2010)	3.087E+8	people	US Census (2018)

* Sum of 2 subcategories
Note: Both SI and IP units are included for impact categories when applicable.

Source: NIST BEES User Manual, 2021

Weighting (Valuation)

- Impact category indicator results are multiplied by weighting factors and added to form a total “environmental performance” score.
- An optional step
- Weights for different impact categories are based on the perceived importance or relevance. ➔ **Subjectivity!**

4 Interpretation

- Present LCA results in a most informative way
- Analyze results
- Reach conclusions
- Explain limitations
- Provide recommendations

Building LCA Requirements

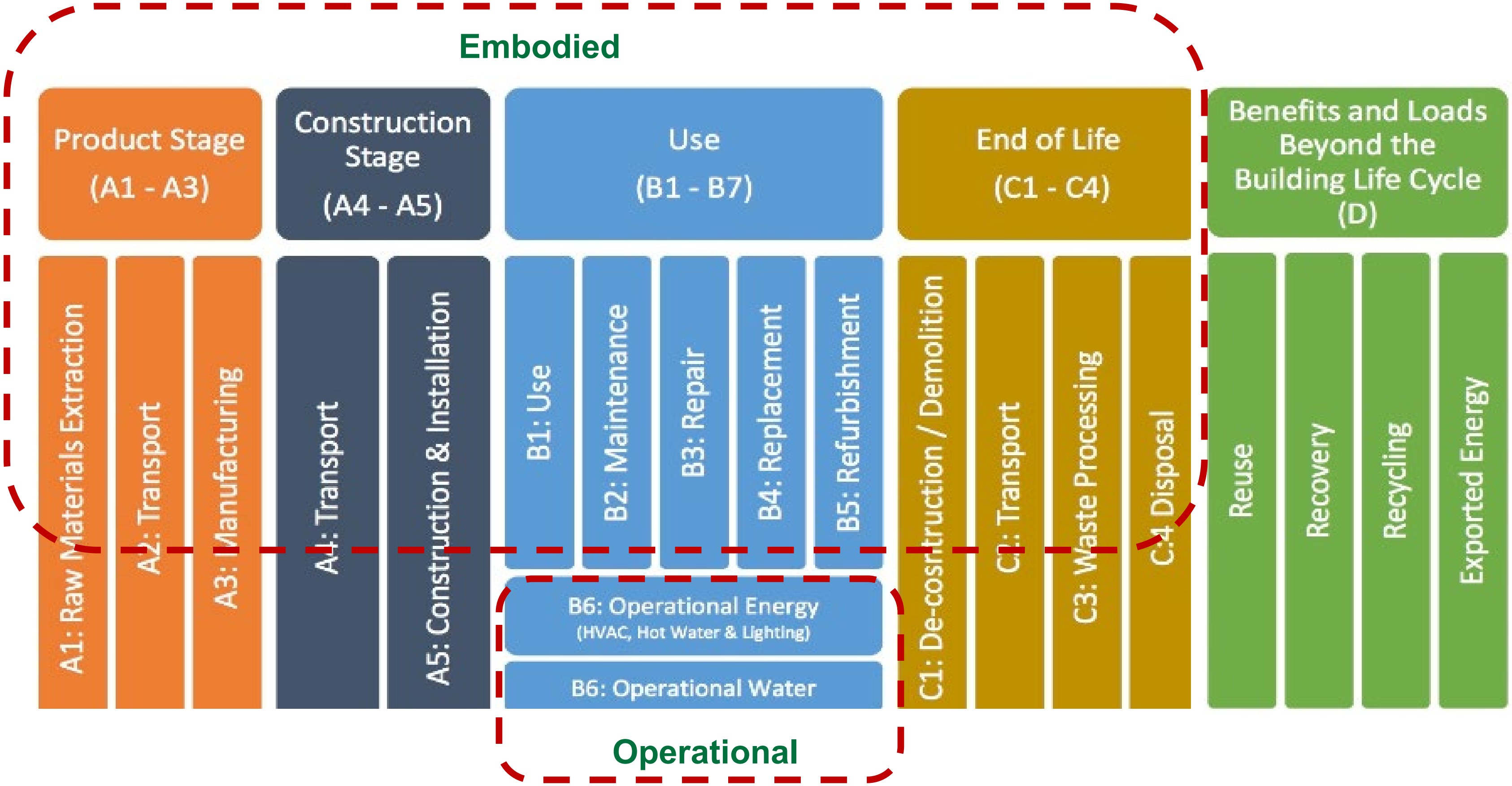
- Green building rating systems such as LEED, Green Globes, and Living Building Challenge. For example, LEED V4.1 (BD+C) has Material and Resources Credits on:
  - Building Life-Cycle Impact Reduction (1-5 points)
  - Environmental Product Declarations (1-2 points)
- High-performance building codes and standards such as International Green Construction Code (IgCC) and ASHRAE 189

Building LCA Applications

- Purposes: design improvement, comparison, declaration, rating and standard compliance
- Project phase at which LCA is performed
- The object of assessment: materials/products, assemblies, whole building
- Life cycle stages to be included

Operational vs. Embodied

- Embodied energy
- Embodied carbon
- Embodied environmental impact



Use EPD for Material and Product Selection

EPD stands for Environmental Product Declaration. An EPD is a public, verified report that documents a product's life cycle environment impacts based on a verified LCA.

- Compliance with ISO Standard 14025
- Adherence to the appropriate industry-standard Product Category Rules (PCRs), specifying how the LCA should be conducted:
    - A clear description of the functional unit
    - A list of the life cycle stages considered in the analysis
    - Impact categories
- Third party certification of the LCA process

Source: https://sftool.gov/plan/402/environmental-product-declarations-epds

EPD Example

- Ready-mixed concrete EPD report

  https://www.nrmca.org/wp-content/uploads/2022/03/NRMCA_EPDV3-2_20220301.pdf

- Ceramic tile EPD report

  https://interceramicusa.com/wp-content/uploads/2021/01/101.1_Tile-Council-of-North-America_EPD_Ceramic-Tile.pdf

- EPD label example (right image)

Environmental Facts Functional unit: 1 m^2 of Ceramic Tile Floor Covering Reference Service Life (RSL): 60 Years	
Life Cycle Inventory Analysis	
Energy Demand	
Primary Renewable (MJ)	10.4
Primary Non-Renewable (MJ)	225
Secondary Renewable (MJ)	0.15
Secondary Non-Renewable (MJ)	1.4
Non-Renewable Material Sources (kg)	51
Waste Output	
Non-Hazardous (kg)	41
Hazardous (kg)	0.0028
60 Year Impact Assessment	
Global Warming Potential (kg CO_2 eq)	15
Acidification Potential (kg SO_2 eq)	0.0565
Ozone Depletion Potential (kg R11 eq)	8.11E-10
Smog Potential (kg Ethene eq)	0.0052
Eutrophication Potential (kg Phosphate eq)	0.00604
Abiotic Depletion Potential - Elemental (kg Sb eq)	1.22E-05
Abiotic Depletion Potential - Fossil (MJ)	219
Boundaries: Cradle to Grave	Clay: 70.3%
Company: North American Tile Manufacturers	Quartz: 4.8%
Product Name: North American-Made Ceramic Tile	Feldspar: 5.3%
Recycled Content: Wide Percentage Range	Scrap: 4.2%
Certification: Some Tiles **Green Squared Certified®**	Kaolin: 3.2%
Other Attributes: Zero VOCs	Granite: 1.3%
	Lime: 1.1%
	Glaze & Stain: 5.4%
	Other Minerals: 4.0%

Building LCA Tools

- Embodied Carbon in Construction Calculator (EC3) Tool

  https://buildingtransparency.org/ec3
- BEES Online 2.1 ➔ building products

  https://ws680.nist.gov/Bees2
- ATHENA Impact Estimator ➔ building products, assemblies, and whole building

  https://calculatelca.com/software/impact-estimator/

Questions & Discussions

Weimin Wang

Email: weimin.wang@uncc.edu

Recommended Readings

- Bayer, C., Gamble, M., Gentry, R. and Joshi, S., 2010. AIA guide to building life cycle assessment in practice. The American Institute of Architects, Washington DC.
- Lewis, M., Huang, M., Carlisle, S. and Simonen, K., Introduction to embodied carbon. https://content.aia.org/sites/default/files/2021-10/21_10_STN_DesignHealth_474805_Embodied_Carbon_Guide_Part1.pdf
- Lewis, M., Huang, M., Carlisle, S. and Simonen, K., Measuring embodied carbon. https://content.aia.org/sites/default/files/2021-10/21_10_STN_DesignHealth_474805_Embodied_Carbon_Guide_Part2.pdf
- Scientific Applications International Corporation (SAIC), Curran, M.A., National Risk Management Research Laboratory (US) and Office of Research and Development, Environmental Protection Agency, United States, 2006. Life-cycle assessment: principles and practice.